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Electrically controlled single quantum dot switching in photonic crystal resonators

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Abstract: The reflectivity of a photonic crystal cavity is modified using a single coupled quantum dot. We demonstrate electrical modulation by controlling the state of the quantum dot using a lateral electric field.

OCIS codes: (270.0270) Quantum optics; (250.6715) Switching; (250.4110) Modulators

Photonic crystals represent one of the most promising platforms for future optoelectronic devices. When combined with single emitters, they can be used to control the flow of light at single photon level. This opens the possibility of engineering a new generation of devices for both classical and quantum information science. Classically, one can create switches or optical logic devices operating at very low power levels. At the same time, a quantum dot in a nanoresonator represents a building block for future quantum information devices based on cavity quantum electrodynamics.

We have recently shown [1] that the reflectivity of a GaAs photonic crystal cavity can be controlled using a single InAs quantum dot coupled to it. This effect can be observed both for the quantum dot in the strong coupling regime and in Purcell regime. When the quantum dot is in Purcell regime, the effect is named dipole-induced transparency. For classical devices, one of the most immediate applications of this effect is to modulate signals by controlling the state of the quantum dot. We have already shown this kind of control in Refs.[1, 2], where the resonance of the quantum dot is controlled by locally changing the temperature of the device [3]. In this case the modulation speed is limited to the inverse of the thermal relaxation time of the device, which in our case is in the MHz range. This speed is orders of magnitude slower than the speeds currently used in optoelectronic devices.

In this paper we show experimentally that the reflectivity of the cavity - quantum dot system can be controlled electrically using a bias voltage that creates a lateral electric field across the cavity. The experimental device consists of a GaAs linear three hole photonic crystal cavity with an InAs quantum dot (see Fig.1 (a)), as described in Ref.[3]. A pair of metallic electrodes are placed around the photonic crystal cavity as shown in Fig.1(b) . The device has a hybrid design that allows control of the system both via local temperature tuning and electric fields.

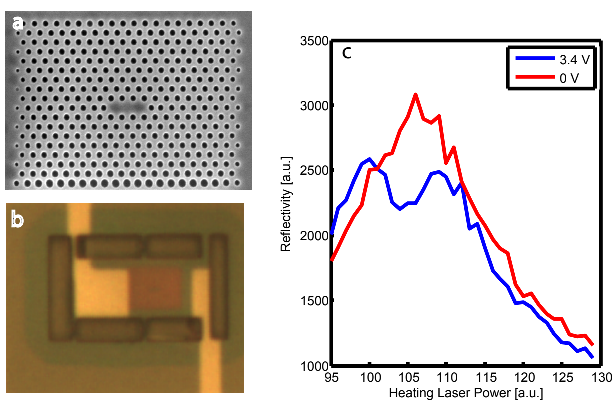

FIG. 1: (a) Scanning electron microscope image of the linear three hole defect cavity (b) Optical microscope image showing the photonic crystal device and the metal electrodes used to apply the lateral electric field. The left electrode also serves as a heating pad for local temperature tuning. (c) Reflectivity spectra taken for different values of the bias voltage. While for zero bias the cavity reflectivity has the regular Lorentzian shape, when applying a bias of 3.4 V a drop in the intensity of the reflected signal occurs due to the presence of the quantum dot.

The presence of the lateral electric field can affect the quantum dot in various ways, depending on the electric field intensity and the position of the quantum dot relative to the electrodes. The quantum dot may experience a DC Stark shift, or it may transition to various charged states [4]. All these effects are usually associated with a change in

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the quantum dot emission wavelength so they can be used to modulate the reflectivity signal.

During the experiment, a coupled quantum dot was identified in a photonic crystal cavity with a quality factor $Q \sim 10000$. Then reflectivity measurements were performed for different values of the bias voltage. The measurements were done as described in Ref.[1] using the local temperature tuning technique. When the bias voltage is tuned from 0 volts to 3.4 volts, the quantum dot changes its state. The plot in Fig.1(c) shows the reflectivity measurements at these two values of the bias voltage. As expected, the change in the quantum dot state is associated with a change in the amplitude of the reflectivity signal, thus proving that electrical modulation of the output signal can be achieved.

One of the most important aspects of a modulator is the speed at which it can perform. Most of the electronic phenomena involving InAs quantum dots in photonic crystal cavities occur at speeds higher than 1 GHz and this is what we also expect from this modulator. Our most recent measurements show that the quantum dots state can be controlled at speeds higher than 100 MHz, limited by the RC constant of the driving electrical circuit. We are currently working on pushing this limit closer to the fundamental limit imposed by the cavity-quantum dot system.

In conclusion, we have shown that the reflectivity of a photonic crystal cavity with a coupled quantum dot can be modulated using a bias electric field that controlls the state of the quantum dot.

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[1] D. Englund, A. Faraon, I. Fushman, N. Stoltz, P. Petroff, and J. Vuckovic. Controlling cavity reflectivity with a single quantum dot. Nature, 450:857–861, 2007.

[2] Andrei Faraon, Ilya Fushman, Dirk Englund, Nick Stoltz, Pierre Petroff, and Jelena Vuckovic. Dipole induced transparency in waveguide coupled photonic crystal cavities. Optics Express, 16:12154–12162, 2008.

[3] A. Faraon, D. Englund, I. Fushman, N. Stoltz, P. Petroff, and J. Vuckovic. Local quantum dot tuning on photonic crystal chips. Applied Physics Letters, 90(213110), 2007.

[4] B. D. Gerardot, S. Seidl, P. A. Dalgarno, R. J. Warburton, D. Granados, J. M. Garcia, K. Kowalik, O. Krebs, K. Karrai, A. Badolato, and P. M. Petroff. Manipulating exciton fine structure in quantum dots with a lateral electric field. Applied Physics Letters, 20(041101), 2007.